Steven S. Zumdahl Chemistry

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Chemistry



D. C. HEATH AND COMPANY

LEXINGTON, MASSACHUSETTS / TORONTO

he first question that comes to mind when looking at a new general chemistry textbook is: how is this book different from all of those others on the shelf? Although this book is not revolutionary in content or style, it does have important differences from the others. There are more figures than in any competing text. Since general chemistry typically gives a highly pictorial view of the chemical concepts with minimal mathematical complications, illustrations and photographs are invaluable.

With an unusually strong problem-solving orientation, this book talks to the student about how to approach and solve chemical problems. A strong pitch is made to the student to use a thoughtful and logical approach rather than to simply memorize procedures. In particular, an innovative method is given for dealing with acid-base equilibria, the material the typical student finds most difficult and frustrating. The key to this approach involves first deciding what species are present in solution and then thinking about the chemical properties of these species. This provides a general framework for approaching all types of solution equilibria.

This book features a thorough treatment of reactions that occur in solution, including acid-base reactions, precipitation reactions, and oxidation-

reduction reactions. Although this material occurs early in the text (Chapter 4), where it can best support the laboratory portion of the course, it can be used in parts if the instructor prefers.

Descriptive chemistry and chemical principles are thoroughly integrated in this text. Chemical models are sterile and confusing without the observations that stimulated their invention. On the other hand, facts without organizing principles seem overwhelming. The observations and models must be integrated to make chemistry interesting and understandable. Also, in those chapters that deal systematically with the chemistry of the elements, there is a continuous effort to show how the properties and models correlate.

A unique feature of this text is the chapter on industrial chemistry (Chapter 24). This chapter describes several chemical industries ranging from the manufacture of polymers to winemaking with the purpose of showing the application of chemical principles in a setting where many factors, such as safety, environmental impact, and economics, must be considered in addition to the chemistry. This material can be used as a whole or individual sections can be used at any point in the course where the instructor feels it is relevant. The *Instructor's Guide* has suggestions on how to use this material.

Throughout the book there is a strong emphasis on models: how they are constructed, how they are tested, and what we learn when they inevitably fail. Models are developed naturally. Pertinent observations are always presented first, to show why a particular model was invented. In addition, chemistry is presented as a human activity carried out by real people, many of whom are described in-text, or in the interest features, called Chemical Impacts.

The end-of-chapter exercises are grouped according to topic. Although the exercises emphasize the fundamental principles, the context is often a real-life application of chemistry. This makes the exercises interesting to the student and provides a means for introducing more descriptive chemistry. The problems in the additional exercises section are not grouped by topic and tend to be more complicated than the earlier ones. This gives the student practice in recognizing the various applications of the concepts covered in the chapter and in synthesizing several concepts.

To make the book more flexible the derivation of the ideal gas law from the kinetic-molecular theory and quantitative analysis using spectroscopy are presented in the appendixes. While this material is typically not covered in a mainstream general chemistry course, it may be appropriate for some courses. The book is aimed at the mainstream course, but it should also be useful in many courses intended for majors. By using the optional material in the appendixes and by assigning the more difficult end-of-chapter exercises (from the additional exercises section) the level of the text should be quite appropriate for many majors courses.

A series of supplements has been designed to make this book more useful to both students and instructors. These include:

- ☐ *Instructor's Guide*, by Kenneth C. Brooks of the University of Colorado at Denver, includes suggested orders of the topics other than that in the text, amplification of strategies used in the various chapters, and answers to problems not found in the *Solutions Manual*.
- ☐ Study Guide, by Martha B. Barrett of the University of Colorado at Denver, is geared to the student and

includes alternate strategies for solving various types of problems, supplemental explanations for the most difficult material, and self tests.

- □ Solutions Guide, by Kenneth C. Brooks of the University of Colorado at Denver, provides detailed solutions for two-thirds of the end-of-chapter exercises (designated by color question numbers or letters) using the strategies emphasized in the text.
- ☐ Experimental Chemistry, by James F. Hall of Northeastern University, Boston, provides a laboratory program compatible with the text. A wide variety of experiments is presented, emphasizing a thoughtful, investigative approach.
- ☐ The Test Item File consists of a diskette containing approximately 1000 exam questions organized according to the chapters in the text. The questions are in multiple-choice and long-answer formats.

Acknowledgments

Many people contributed tremendously to this text. I especially want to thank Mary Le Quesne, Acquisitions Editor, whose endless good humor, enthusiasm, and knowledge made this project a great pleasure. I also want to thank Peggy J. Flanagan, Senior Production Editor, whose professionalism and powers of organization were flawless in the face of a seemingly impossible task. I owe much to Ken Brooks, who collaborated in writing the end-ofchapter exercises and who contributed immeasurably to the project through his enthusiastic attitude and unerring suggestions concerning content and approach. In addition I want to thank Bruce Averill, Professor of Chemistry at the University of Virginia, who provided expert advice and valuable constructive criticism as the principle reviewer of the text. Roxy Wilson did an excellent job setting up laboratory demonstrations for several of the photographs in the book. I especially appreciate the contributions of Eunice Doden Zumdahl, who typed the first draft of manuscript, helped proofread the galleys and page proofs, and was supportive in every possible way. I am grateful to Whitney and Leslie for their patience during the many times I had to miss their activities because of "the book."

Many other people at D. C. Heath provided invaluable assistance during this project: Tom Flaherty, Director of Sales and Marketing, provided the support necessary to ensure a modern, high-quality product; Fay Torresyap, Photo Editor, found the beautiful and useful photos that appear throughout the text; Margaret Gage, Advertising Manager, produced creative and informative sales literature; Ed Catania, Manager of Design, Manufacturing, and Production, supervised the production of the text; Kate Bramer and Jean Curran typed the intermediate drafts from incredibly difficult manuscript copy.

Finally, I want to extend special thanks to the following people who reviewed all or part of the manuscript at its various stages: Bruce Averill, University of Virginia; O. T. Beachley, Jr., SUNY at Buffalo;

Jon M. Bellama, University of Maryland; David Dixon, Du Pont Company (formerly of University of Minnesota); Lawrence Epstein, University of Pittsburgh; Henry C. Griffin, University of Michigan; James C. Hill, California State University; Joseph Kanamueller, Western Michigan University; Philip Lamprey, University of Lowell; Edwin Larsen, University of Wisconsin; C. Weldon Matthews, Ohio State University; Ronald McClung, The University of Alberta; Clinton Medbury, Citadel Military College of South Carolina; Leon O. Morgan, University of Texas; and Russell F. Trimble, Southern Illinois University.

I would very much appreciate comments and suggestions for improvement as you and your students use the book.

f you are typical of most students, you are probably worried about how you will do in this chemistry course. Learning chemistry is difficult; almost everyone seems to agree on that. In fact, learning chemistry can be so frustrating that it is easy to lose sight of how really important and interesting the subject is. You can learn chemistry and even enjoy the process, but you must understand that finesse works much better than brute force. Chemistry is difficult not so much because the concepts are hard, but because it deals with complicated systems. Before a problem can be solved a lot of facts must be sifted to find the pertinent ones. There is no alternative to thinking things through.

The major purpose of this book, of course, is to help you learn chemistry. However, this main thrust is closely linked to two other goals: to show how important and how interesting the subject is; and to show how to think like a chemist. To solve complicated problems the chemist uses logic, trial and error, intuition, and above all, patience. A chemist is used to being wrong. The important thing is to learn from a mistake, recheck assumptions, and try again. A chemist thrives on puzzles that seem to defy solutions.

The non-chemist can benefit from the chemist's attitude. Problem-solving is important in all professions and in all walks of life. That is, the techniques

useful in solving chemistry problems are also applicable to "real life." Thus, I believe that the study of chemistry has much to offer the non-major, including an understanding of many fascinating and important phenomena and a chance to hone problem-solving skills.

This book attempts to present chemistry in a manner that is sensible to the novice. Chemistry is not the result of an inspired vision. It is the product of countless observations and many attempts, using logic and trial and error to account for these observations. In this book the concepts are developed in a natural way: the observations come first and then models are constructed to explain the observed behavior.

Models are a central theme in this book. The uses and limitations of models are emphasized and science is treated as a human activity, subject to all the normal human foibles. Mistakes are discussed as well as successes.

Another central theme of this book is a thoughtful, systematic approach to problem-solving. Learning is much more than memorizing facts. Truly educated people can use their factual knowledge as a starting point—a base for creative approaches to solving problems.

We have tried to ensure that the ideas in this book are presented as clearly as possible. However,

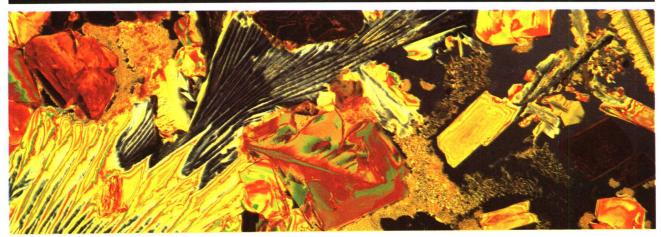
learning chemistry requires real study: several careful readings of the material in the text, thorough examination of the worked-out sample exercises, and working the end-of-chapter exercises assigned by your professor. Answers to selected exercises are in the back of the book. Answers to exercises with color question numbers or letters are in the *Solutions Guide*.

It is very important to use the exercises to your best advantage. Your main goal should not be to simply get the correct answer but to *understand* the process for getting the answer. Memorizing the solutions for specific problems is not a very good way to prepare for an exam. Chemical systems are complex enough that a small change can mean a problem that looks very similar to one you have memorized actually requires a very different type of solution. The

point is that there are too many pigeonholes required to cover every possible problem type. If you are to succeed, you must take the attitude that every problem is unique and requires a thoughtful approach. Look within the problem for the solution. Use the concepts you have learned along with a systematic, logical approach to find the solution. Learn to trust yourself to think it out. Do not just memorize everything in sight out of desperation. You will make mistakes as you try to figure things out, but the important thing is to learn from these errors. The only way to gain confidence is to do lots of practice problems and use these to diagnose your weaknesses.

Be patient, be thoughtful, and work hard to understand rather than simply memorize. I wish you a satisfying and interesting year.

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Chemical Foundations

hemistry deals with all the materials of the universe and the changes that these materials undergo. Practitioners of this broad discipline are involved in activities as diverse as looking for molecules in space, exploring the fundamental particles of matter, making new materials, and trying to find out how organisms, such as humans, work. Chemists deal with many different phenomena and do research to try to solve a wide variety of problems. These are a few of the questions that chemists are currently considering:

How can DNA be modified to cure diseases such as sickle-cell anemia and diabetes?

What causes acid rain, and how can it be prevented?

What pollutants are present in the Mississippi River, which is the source of drinking water for New Orleans?

Can safe pesticides be synthesized?

Can our large supplies of coal be economically turned into natural gas?

Why do certain chemicals cause cancer?

Do the chemicals used as refrigerants pose a danger to the protective ozone layer in the atmosphere?

How does lithium affect mental health?

Can batteries be designed that would make electric cars feasible? How can bacteria be modified so that they produce useful chemicals, such as insulin?

Figure 1.1 on the following page shows two of the diverse areas in which chemists participate.

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- 1.1 The Scientific Method
- 1.2 Units of Measurement
- 1.3 Uncertainty in Measurement Precision and Accuracy
- 1.4 Significant Figures and Calculations
- 1.5 Dimensional Analysis
- 1.6 Temperature
- 1.7 Density
- 1.8 Classification of Matter
- 1.9 Separation of Mixtures



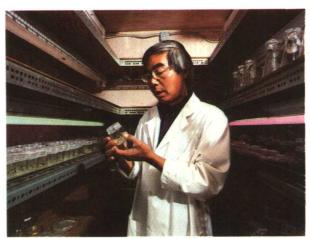


Figure 1.1.Chemists at work.

This text stresses thoughtful problem solving rather than rote memorization.

Chemical knowledge is expanding at a phenomenal rate. At present nearly 400,000 research reports in the various areas of chemistry are published each year. This amounts to more than a thousand articles per day. Clearly it is not humanly possible to master the entirety of chemical knowledge; however, it is important to understand at least the basics of chemistry. Chemistry is at the heart of the processes that sustain our life and allow us to learn, work, keep warm, and travel. In fact, chemistry is vital to most of the activities of our lives. Understanding the chemical processes that maintain life and control the events in the world around us is essential to our continued well-being.

This textbook introduces you to the types of problems chemists deal with and the methods and models used to solve them. A major goal of this book is to acquaint you with the fundamental assumptions that chemists make in describing the behavior of matter and how these principles are used to solve real-life problems. Another goal is to help you become a better problem solver. As you will see, chemical systems tend to be complex, but critical thought, intelligent approximations, and creative use of fundamental knowledge can make them comprehensible. You cannot simply rely on memorization. You have to *think* to solve chemistry problems. This makes chemistry challenging and sometimes frustrating but also gives you a chance to improve your problem-solving skills, which will come in handy in other parts of your life.

Thus this textbook will

- 1. help you understand the fundamental models of chemistry,
- 2. show you how chemistry is involved in the real world, and
- 3. help you develop your skills as a problem solver.

In this chapter we will develop a general idea of science as a discipline and will demonstrate how to handle one of the most important tools of science, the measurement.

1.1 The Scientific Method

PURPOSE

To identify the principal operations and limitations of the scientific method.

A science such as chemistry grows and progresses by use of the scientific method. This approach in its simplest form consists of several distinct operations:

- 1. Making observations. The observations may be qualitative (the sky is blue; mercury is a liquid at room temperature) or quantitative (the pressure of the gas is 1 atmosphere; the temperature of the water is 54°C). A quantitative observation is called a measurement. We will discuss measurements in more detail later.
- 2. Looking for patterns in the observations. This process often results in the formulation of a natural law. A natural law is a statement that expresses generally observed behavior. For example, studies of innumerable chemical reactions have shown that the substances present after a reaction have the same total mass as that of the substances present before the reaction took place. These observations can be generalized as a natural law called the law of conservation of mass.

A natural law is often stated in terms of a mathematical formula. For example, Robert Boyle (Fig. 1.2) observed that under certain conditions the volume of a gas is inversely proportional to its pressure. This can be stated symbolically as

$$V \propto \frac{1}{P}$$

where V represents the gas volume, P represents the pressure of the gas, and the symbol ∝ means "proportional to."

A second formula that states the same law is

$$V = k \left(\frac{1}{P}\right)$$

where k is called the proportionality constant.

- 3. Formulating theories. A theory (often called a model) consists of a set of assumptions put forth to explain the observed behavior of matter. At first the set of assumptions is often called a **hypothesis**. If the tentative hypothesis survives the tests of many experiments, we gain confidence in its value and call it a theory or a model. It is important to distinguish between observations and theories. An observation is a fact that endures. The accuracy of a measurement may be increased by the development of a more sensitive measuring device, but the measurement should always remain fundamentally the same. A theory is an interpretation—a speculation—as to why nature behaves in a particular way. Theories inevitably change as more facts become known. An example of this process is given in the Chemical Impact feature in this chapter.
- 4. Designing experiments to test the theories. Ideally, science is self-correcting, continuously testing its models. It is important to remember that models are human inventions. They are an attempt to explain observed natural behavior in terms of ideas from human experience. Models by their very nature are imper-



Figure 1.2.

Robert Boyle (1627-1691) was born in Ireland. He became especially interested in experiments involving air and developed an air pump with which he produced evacuated cylinders. He used these cylinders to show that a feather and a lump of lead fall at the same rate in the absence of air resistance and that sound cannot be produced in a vacuum. His most famous experiments involved careful measurements of the volume of a gas as a function of pressure. In his book The Sceptical Chemist, Boyle urged that the ancient view of elements as mystical substances should be abandoned and that an element should instead be defined as anything that cannot be broken down into simpler substances. This conception was an important step in the development of modern chemistry.